GEOMEMBRANE/GCL COMPOSITE FINAL COVER FOR A HAZARDOUS WASTE LANDFILL

A final cover cross section for a hazardous waste landfill was revised to incorporate a needlepunched nonwoven GCL overlain by a 40mil-textured HDPE geomembrane instead of a 24-inch thick compacted clay layer. An evaluation determined that a GCL provided superior performance while accelerating construction and reducing overall costs.

Replacement of the 24 inch thick compacted clay layer with that of an equivalent much thinner GCL increased the facility capacity by 55,000 m^3. The savings in airspace generated additional revenue in the range of \$5.7 million to \$7.2 million when considering a tipping fee of \$105/m^3 to \$130/m^3 for hazardous waste. The GCL cover system was also much easier to construct than a compacted clay layer. When comparing the costs of constructing these two systems, a savings of \$42,000/acre resulted with the use of a GCL/Geomembrane final cover system.

Finally, when 78% of the landfill had been covered with the GCL/Geomembrane cover, leachate generation had been reduced by approximately 71% resulting in a drastic reduction in the cost of leachate treatment.

To conclude, it is obvious that the use of a GCL in place of a compacted clay layer in a hazardous waste landfill will result in a tremendous cost savings and improved performance.

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GEOMEMBRANE/GCL COMPOSITE FINAL COVER FOR A HAZARDOUS WASTE LANDFILL

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ABSTRACT

The incorporation of a geosynthetic clay liner (GCL) in the closure of a permitted hazardous waste landfill resulted in both an increase in waste disposal capacity and a reduction in final cover construction costs. The state regulatory authority required a composite final cover. The cross section originally designed for the site consisted of a 60 cm (24-inch) compacted clay layer overlain by a 40-mil textured geomembrane overlain by 1.1 m (42 inches) of protection soil, and 15 cm (6 inches) of topsoil.

The final cover cross-section was revised to a total of 0.8 m (30 inches) consisting of a needlepunched nonwoven GCL, overlain by a 40-mil textured geomembrane overlain by a 30 cm (12 inch) drainage layer, 30 cm (12 inches) of protection soil, and 15 cm (6 inches) of topsoil. The equivalency issues evaluated included hydraulic issues, physical/mechanical issues, construction issues, and economic issues. An evaluation determined the GCL provided superior performance to a compacted clay liner while accelerating construction and reducing overall costs.

INTRODUCTION

As a component of its materials management system, a major New York industrial manufacturer maintains an active Hazardous Waste Disposal Unit at its facility. This Disposal Unit is necessary to accept hazardous by-products of its manufacturing and on-site waste water treatment processes. As the permitted air-space of this facility was depleted, IT reviewed opportunities to modify the landfill design to extend site life and defer the expense associated with the construction of a new landfill facility.

- In 1995, a permit modification application was prepared for the vertical expansion of the facility. The permit modification application had three fundamental components and included the following changes to the permitted design: An increase in the facility sideslopes from the currently permitted slopes of 4H:1V and 5H:1V to 3H:1V (the maximum allowed by regulation) and a 3 meter (10-foot) increase in the top elevation of the landfill. These changes increased facility capacity by 30,000 m^3 (39,000 cubic yards).
- Replacement of the 60 cm (24-inch) low permeability soil layer with an equivalent geosynthetic clay liner (GCL). This change increased facility capacity by 14,000 m^3 (19,000 cubic yards).
- Reduction in the total thickness of cover soils above the liner from 1.2 m (4 feet) to 0.8 m (2.5 feet). This change increased facility capacity by 11,000 m^3 (14,000 cubic yards).

These modifications, shown in Figure 1, resulted in a total landfill capacity increase of 55,000 m^3 (72,000 cubic yards). While not a huge increase for typical landfills, the hazardous waste capacity is at a premium and the above modifications effectively extended hazardous waste disposal capacity within this landfill for an additional five years. The key to the modification was the use of a GCL in place of compacted clay in the cover design. This paper will focus on the considerations addressed in evaluating the use of a GCL in place of compacted clay.

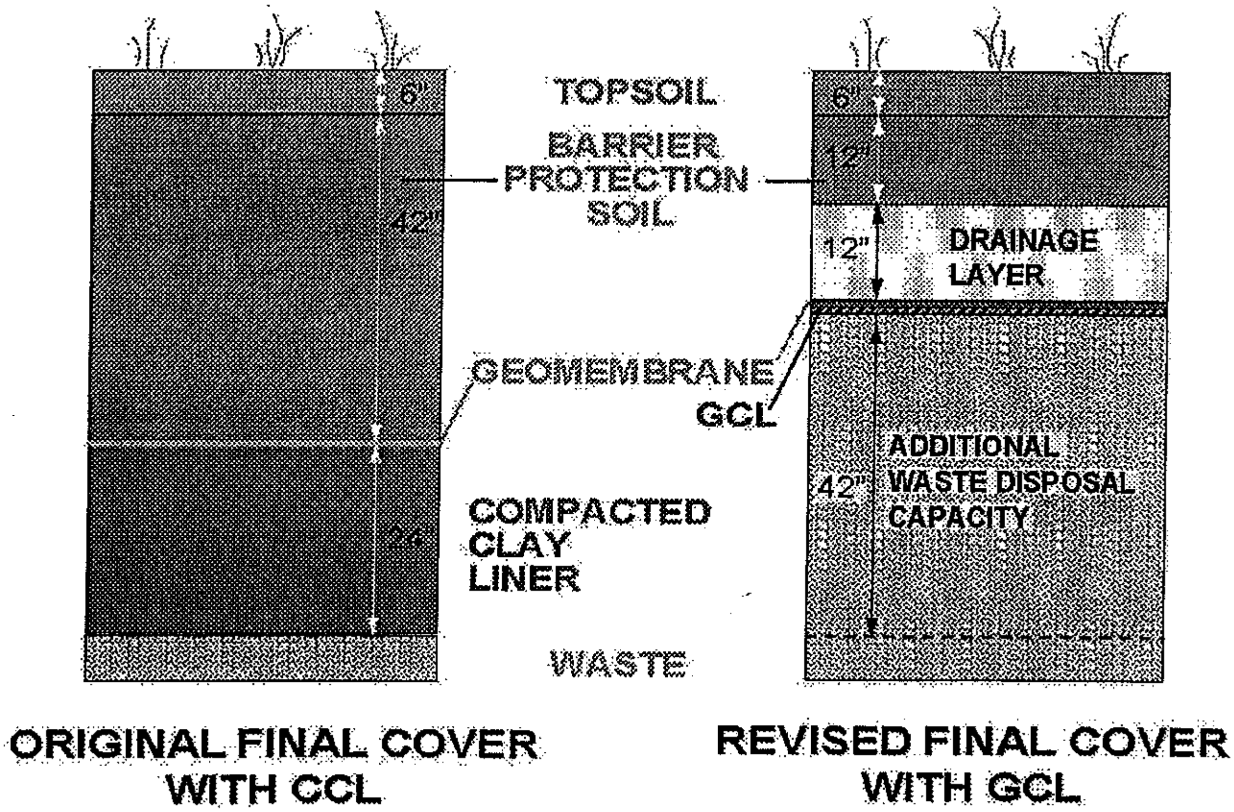

Figure 1. Original and Revised Final Cover Designs

GEOSYNTHETIC CLAY LINERS

A GCL is a factory manufactured hydraulic barrier that consists of a layer of sodium bentonite bonded to one or more geosynthetics. There are several different types of GCLs currently produced in the United States, 1) bentonite adhesive-bonded to two geotextiles, 2) bentonite needlepunch-bonded between two geotextiles, 3) a membrane laminated to one of the above, and 4) bentonite adhesive-bonded to a geomembrane.

Bentonite is primarily composed of montmorillonite, a high swelling clay. Under a confining pressure of 35 kPa (5 psi) GCLs have a hydraulic conductivity of $< 5 \times 10^{-9}$ cm/s. Since their introduction in the 1980s, GCLs have become a common material in the design of landfill liners as an alternative to compacted clay liners. Due to final cover stability concerns, a double-nonwoven needlepunched GCL was chosen for evaluation as the alternative in this project.

DESIGN CONSIDERATIONS

The design considerations for the modifications described above, included global landfill stability, final cover stability, protection of final cover barrier layers from freeze/thaw damage and equivalency of cover barriers.

A cross-section was developed using the information from the site topographic mapping, as-built baseline topography for the landfill, the hydrogeologic investigation, the existing grade of waste, and the proposed final grade of the landfill. The slope stability analyses were primarily based on this cross-section.

Because of the relatively low strength of the silty clay layer and the low interface strengths of the baseliner system, the global stability analysis focused on the following:

- The stability of the base soil underlying the baseliner of the landfill
- The stability of the side slopes
- The stability of the baseliner system

The global stability analyses of the landfill were performed using the computer program, PCSTABL5M, developed by Purdue University. This program is capable of conducting two-dimensional slope stability analysis under various circumstances. Seismic stability analyses were also conducted on the long-term global stability of the landfill.

The final cover stability calculations were performed using the infinite slope stability approach. Based upon the proposed final cover profile, stability of the proposed cap is controlled by three primary factors:

- The shear strength of the various interfaces and the internal shear strength of the GCL,
- The shear strength of the soils used above the geomembrane,
- The development of seepage forces or pore pressures above the geomembrane associated with infiltration from rainfall.

The behavior of the geomembrane soil interface is well understood and has been documented many times since the use of geomembrane caps first began. Of greater interest in the design was the interface between the GCL and the geomembrane and the shear forces that may pass directly through the GCL.

GCL DIRECT SHEAR TESTING

Based upon previous discussions and submissions to the NYDEC, the minimum factor of safety against sliding that would be acceptable was 1.25. This factor of safety was based upon the engineered nature of all the products used, the repairable nature of any damage that may occur in the cap and the limited consequences of any failure in the cap with respect to potential loss of life or irreversible damage to the environment.

The stability of the proposed composite cap containing the GCL was evaluated. Two interface direct shear tests were performed at normal loads of 7.5, 15 and 25 kPa (150, 300 and 500 psf) between the 40-mil textured geomembrane and a double-nonwoven needlepunched GCL with no fiber melting process. The design analyses incorporated data from recent laboratory test results of the materials proposed for construction. The results of these analyses supported factors of safety in excess of 1.25 based upon the residual interface shear strengths. Conformance testing of materials supplied for construction exceeded minimum strength requirements. Conformance testing yielded peak friction angles of 37.5 and 32 degrees with respective cohesion values of 118 psf and 111psf. Residual friction angles of 27.1 and 18.5 degrees were measured with cohesion intercepts of 51 psf and 80 psf, respectively.

Internal shear was not considered to be the critical factor for needlepunched GCLs placed against geomembranes at low normal stresses. An EPA sponsored large-scale field study that was in progress at the time of design did not show any internal shear failures for needlepunched GCLs on 2H:1V slopes (Koerner et al., 1996). When loaded in the shear testing apparatus, the GCL/other interface can be constructed to have a multi interface sandwich consisting of the two layers of geotextile, the bentonite, and the other material being tested. In all cases, the GCL/other interface failed before failing the GCL internally. As a result, the internal strength of the GCL is considered greater than the interface strength at relatively low (15 kPa) loads. Also, historical internal direct shear data from an independent laboratory for the double-nonwoven needlepunched GCL under low normal loads had yielded a 44 degree friction angle.

FREEZE/THAW

Based upon the molecular composition of bentonite as well as the results of laboratory and field testing, no impact to the GCL's hydraulic properties due to freeze/thaw is expected. This is due to the weak interbonding in montmorillonite clays that results in interlayer expansion whenever polar molecules, such as water, are available. This is quite in contrast to most naturally occurring clays in the Northeast U.S., which do not expand or swell in the presence of free water. This results in the development in compacted clay of increased permeability upon successive freeze/thaw cycles due to flow channels created by the formation of micro lenses during the freezing process. The moisture that forms the micro lens is drawn from the surrounding clay peds, desiccating the clay. For non-montmorillonite clays, these desiccated zones do not significantly swell upon release of the moisture during thawing. This results in an increase in permeability. Comparatively, bentonite, a montmorillonitic clay, does swell upon thawing and therefore would not be expected to exhibit an increase in permeability associated with freeze-thaw cycles.

Several laboratory and field tests have been performed on geosynthetic clay liners and compacted clay liners, to specifically analyze the affects of freeze/thaw cycles on them. Reports and papers have been written based upon these results. Specifically, Nelson (1993) demonstrated by laboratory testing that the permeability characteristics of a GCL product do not appear to be affected by exposure to multiple freeze/thaw cycles. Kraus et al. (1997) demonstrated by laboratory and field testing that the hydraulic conductivity of needlepunched GCLs did not change significantly after freezing and thawing through one winter. However, Benson et al. (1995) and Chamberlain et al. (1995) have shown through field and laboratory studies that compacted clay does form micro cracks that do not heal upon thawing resulting in increased permeability.

It is evident from this literature that GCLs outperform compacted clay liners with respect to freeze-thaw. Therefore, the thickness of the cover soil of the final cover could be reduced.

EQUIVALENCY

The NYDEC prescriptive cover is a composite cover consisting of 60 cm (24 inches) of compacted clay, with a permeability of no greater than 1×10^{-7} cm/s, overlain by a geomembrane. The idea of using a geomembrane over a clay liner to form a composite liner takes advantage of the beneficial properties of each of the materials in a synergistic manner. The geomembrane provides the primary impermeability of the lining system. Small defects in the geomembrane can be backed up and blinded off by the clay, greatly reducing the leakage potential. In effect, the geomembrane limits flow through the clay liner to relatively small areas.

The specific issues for a technical comparison of GCLs to compacted clay liners have been well documented and presented in literature by Koerner and Daniel (1993). The issues can be divided into two categories: hydraulic and physical/mechanical.

Empirical modeling and field monitoring (Giroud, et al., 1997) have demonstrated that leakage through a circular hole in a geomembrane is a function of the underlying clay permeability, liquid head above the hole, hole size, and degree of intimate contact between the geomembrane and the soil. Leakage rates can be theoretically predicted according to the following equation:

$$Q = C\,[1 + 0.1(h_w/t_s)^{0.95}]\,a^{0.1}\,h_w^{0.9}\,k_s^{0.74} \tag{1}$$

Where Q = rate of leakage through a hole; C = a constant related to the quality of the intimate contact between the geomembrane and the underlying clay liner; a = area of hole in geomembrane; h_w = head of liquid on top of the geomembrane; t_s = clay liner thickness and k_s = permeability of the underlying clay liner.

By inspection of the parameters involved in equation (1), it can be deduced that the possibilities of reducing potential liner leakage in terms of the soil component of a composite liner are related to the quality of its surface for creating an intimate interface with the overlying geomembrane and its permeability.

A paper by Harpur, et al. (1993) describes experiments that were performed on five different GCLs to evaluate the quality of their intimate contact with geomembranes in terms of hydraulic transmissivity along the contact. They present a very revealing graph that demonstrates the effectiveness of a GCL in limiting the horizontal flow of liquid coming through a defect in a geomembrane. The graph indicates that GCLs would be 2 to 3 orders of magnitude more effective in reducing horizontal transmissivity than theoretically excellent field conditions with a compacted clay liner. This would have a direct impact on the amount of leakage that would occur through a geomembrane defect.

The permeability of needlepunched GCL, even at low normal loads, has been shown to be on the order of 5 x 10^{-9} cm/s (Estornell and Daniel, 1992). This compares favorably to the prescriptive compacted clay liner permeability of 1 x 10^{-7} cm/s.

Thus, regarding liner leakage through geomembrane defects, the above analysis indicates that GCLs are at least technically equivalent, and most likely superior, to compacted clay liners. This is supported by an EPA funded study of actual leakage through double-lined composite liner systems in municipal solid waste landfills. Data (Bonaparte et al., 1999) indicates that geomembrane/GCL composite liner systems yielded the lowest flow in leachate detection systems in both active and post-closure cells.

From a physical/mechanical perspective, the most important factor for the final cover is differential settlement. Differential settlement could result in separation, cracking or tearing of various elements of the final cover system. In a related sense, deformation from a seismic event, could cause defects or failures in liner elements in a similar manner to differential settlement.

Koerner and Daniel (1993) describe reports and tests that document needlepunched GCL's ability to withstand relatively high levels of tensile strain (on the order of 10 to 15 percent) without undergoing significant increases in permeability. Standard compacted clay liners, on the other hand, generally cannot tolerate strains approaching one percent without cracking. GCLs are generally considered superior to compacted clay liners in terms of their ability to resist damage from deformation. Slope stability and freeze/thaw behavior are other key elements in the equivalency demonstration. These elements, discussed previously, also indicated that the GCL is equivalent, or superior, to compacted clay.

CONSTRUCTION ISSUES

The final cover was constructed in several phases. Phase I was completed in July 1997, Phase II was constructed in July of 1998, and Phase III was constructed in May of 1999. Construction issues, when comparing GCLs to compacted clay liners, include subgrade preparation, material availability, speed and ease of installation, and construction quality assurance.

A GCL's relative thinness requires that more attention be given to subgrade preparation than for a compacted clay liner. The subgrade for the GCL was the in-place soil-like hazardous waste material. This material is a fine-grained soil-like material that when delivered for disposal contained no sharp stones or other objects that could damage the liner. This material was graded to a 3H:1V (33%) slope and covered with a temporary tarp to shed rainwater until the final cover construction was initiated. Prior to GCL placement, the deployment area was inspected and hand picked for large or sharp objects which may have been included with the waste during the process of landfilling and that might damage the liner. After grading and inspection of the subgrade, the GCL could be safely pulled over the waste surface without damage.

Although the additional attention to subgrade preparation may appear at first to be a disadvantage for a GCL compared to a compacted clay liner; it is actually an advantage. The reason for this is that the most critical subgrade preparation is for the geomembrane. In the case of a compacted clay liner, this means the top surface of the clay liner requires very careful finishing. This is often difficult, requires special equipment, and is often at odds with the aim of covering up the clay as soon as possible to reduce desiccation.

In the case of GCLs, the subgrade can be smoothed out to fit the convenience of the construction schedule without worrying about moisture loss. Even though the same subgrade preparation specifications would be used for the GCL as would be used for a geomembrane, it is actually slightly less critical because of the cushioning effect of the GCL. The surface of the GCL will be much more ideal for a composite liner than the finished compacted clay surface.

Regarding material availability, needlepunched GCLs are readily available from two suppliers.

A GCL can be installed much quicker and easier than a compacted clay liner. Once the GCL material is approved through manufacturers' certifications, conformance testing and on site inspection, its installation is very quick and straightforward. As shown in Figure 2, a backhoe with spreader bar attachment and a four-wheel all-terrain vehicle were used to initially deploy the GCL. A work crew then moved the GCL into final position and placed bentonite between the overlapping seams. In good weather, a crew can typically install one and one-half acres a day with production often limited by the geomembrane installation.

Figure 2. Geosynthetic Clay Liner Deployment

The most critical item during installation is to prevent excessive hydration of the GCL prior to loading. Hydration sources come from precipitation before the GCL is covered with the geomembrane and moisture absorbed from the subgrade waste. Hydration from precipitation was controlled by covering all in-place GCL with geomembrane on the same day that it was deployed (Figure 3).

Hydration from moisture in the subgrade materials is somewhat less defined. If the GCL hydrates before the soil cover is placed, adequate strength can not be guaranteed to support the soils and the placement equipment. Therefore it is necessary to place the soil cover in a timely fashion. In general, a window of 10 to 20 days is available between the time of GCL placement

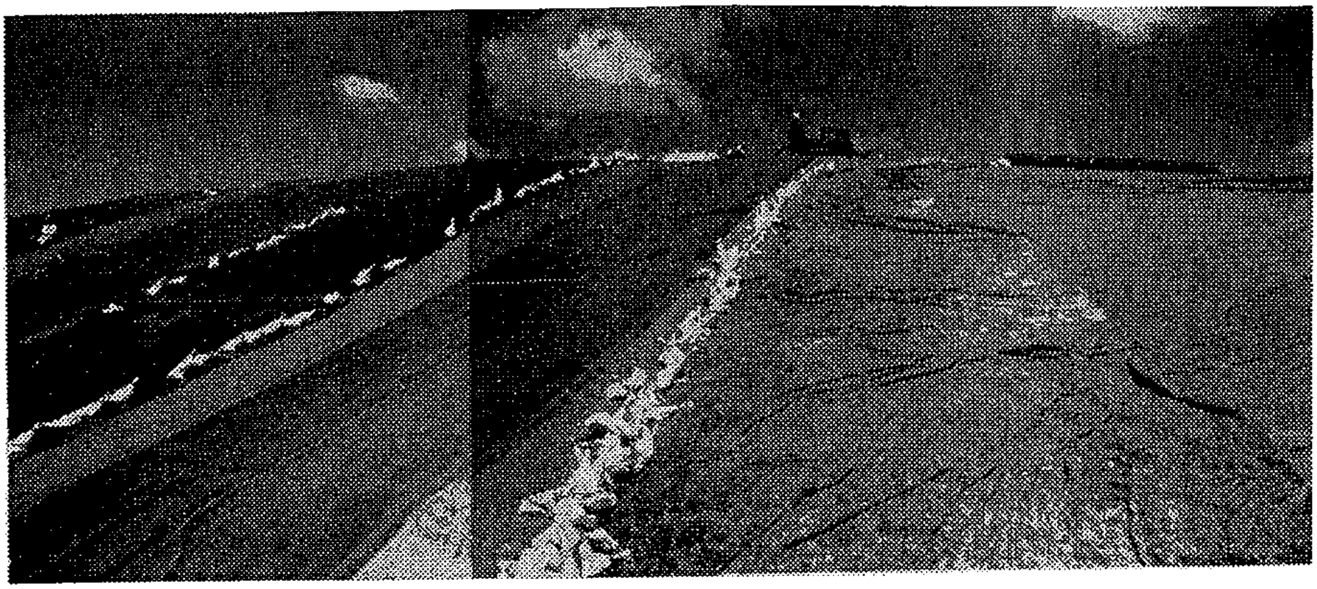

Figure 3. Layers of Geomembrane, Geosynthetic Clay Liner, Subgrade and Tarp

and the need to have cover soils in place. All placement of soils in the final cover was performed within this window with no stability issues.

Comparatively, a compacted clay liner must be moisture conditioned, compacted in lifts at controlled moistures and densities, inspected for good lift bonding and breakdown of clods, and finished smooth enough for overlaying of a geomembrane.

In general, both a GCL and compacted clay liner can be satisfactorily constructed during moderate weather. However, during wet, rainy weather neither a GCL nor a compacted clay liner can be installed. During hot, dry weather a GCL would be superior to a compacted clay liner. While this type of weather is actually advantageous to a GCL, it would tend to desiccate a compacted clay liner.

COST ANALYSIS

The GCL barrier layer was overall less costly to construct than the compacted clay barrier. The actual construction cost paid to the contractor to construct the GCL final cover was \$112,000 per acre. This cost includes all of the soil and geosynthetic components of the final cover but is exclusive of other ancillary activities associated with the construction. By comparison, using the same unit rates, the cost to construct the final cover with the recompacted clay barrier would have been \$154,000 per acre. The direct savings in construction cost were determined to be \$42,000 per acre. This cost difference is specific to construction and does not include the value of the additional waste disposal capacity created through the implementation of this modification.

There are five aspects of cost to consider when comparing the overall costs of the original compacted clay liner/geomembrane composite final cover to the revised GCL/geomembrane composite final cover:

- Material Quantities
- Material Cost (Material, Transportation, Installation)
- Construction Time
- Construction Quality Control (CQC) and Construction Quality Assurance (CQA) Cost
- Airspace

The revised final cover design reduced the overall quantity of material that was incorporated into the closure. In total, the cover soil thickness was reduced from 1.2 m (48 inches) to 0.8 m (30 inches). Therefore a total of 1,850 cubic meters (2,420 cubic yards) of material per acre were saved.

The comparison of the cost of the materials suggests that due to the reasonable availability of naturally occurring clay in the area of the project site, the unit cost per square foot of barrier layer were essentially equivalent. If clay soils had to be purchased from off-site, the GCL would have been less expensive. All other material prices were equivalent between the two final cover cross-sections.

The time required to construct the GCL barrier layer is significantly less than the time required to construct a recompacted clay barrier layer. This reduction in contract time is reflected in the contractor's unit prices for various activities. Savings in "G&A", General and Administrative costs throughout the period of construction were not accounted for in this assessment.

The differential in construction quality control costs were minimal compared to the other parameters. However it is necessary to note that as a reduction in construction time, CQA costs would also be lower for the revised final cover cross-section.

The airspace savings were a key element. Air space for the disposal of Hazardous Waste is at a premium. At the time of this evaluation, the cost for trucking and off-site disposal at a commercial facility is on the order of \$105 to \$130 per cubic meter (\$80 to \$100 per cubic yard). Therefore the commercial value of the air space generated by this design change is in the range of \$5.7 million to \$7.2 million. Without the airspace savings, waste would need to be sent to an off-site disposal facility or another cell would have to be constructed. Both options represent a significant increase in cost over the option selected.

PERFORMANCE

Performance of the composite landfill final cover has been excellent. The measured quantities of leachate collected at the facility have decreased dramatically with the introduction of the final cover. Leachate generation is monitored very closely at this facility. Daily leachate generation data is monitored and reported to NYSDEC on a monthly basis. The first phase of construction was performed in the Spring of 1997. Prior to final cover construction, an average of 867,000 liters (229,000 gallons) of leachate were collected each month (approximately 13,000 lphd or 1,400 gpad). Upon the completion of the Phase I final cover construction, leachate generation dropped to an average of approximately 352,000 liters (93,000 gallons) per month (5,200 lphd or 560 gpad). With the completion of the Phase III final cover construction in May of 1999, leachate generation was reduced to approximately 250,000 liters (66,000 gallons) per month (3,700 lphd or 400 gpad).

It is interesting to note that the reduction in leachate generation observed with this waste material appeared to correspond directly with the placement of the final cover. At the point of completion of the Phase III final cover, approximately 78% of the landfill had received final cover and leachate generation had been reduced by approximately 71% indicating a very close correlation.

CONCLUSION

The use of a GCL in place of a compacted clay liner in a hazardous waste landfill cover design resulted in significant cost savings, accelerated construction time, and improved performance over compacted clay liners.

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